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This final technical report summarizes the work done between 16 Feb 94 and 31 Dec 94 or accomplishments achieved as a result of this work. Finite-Difference Time-Domain code was developed to study acoustic propagation in a shallow water environment. Code was also written to render and display the results of simulations.



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**ONR FINAL TECHNICAL REPORT**

Title: Monte Carlo Simulations of Acoustic Propagation through Shallow Water

Grant No.: N00014-94-1-0469

PIs: Shira L. Broschat, John B. Schneider, and Patrick J. Flynn

## I. Summary

An understanding of the scattering physics involved in high-frequency acoustic propagation through shallow water is important to the Navy (for example, in Mine Countermeasure operations). Degradation of an acoustic signal by clutter makes it difficult to image objects suspended in the water, lying on the bottom, or partially or completely buried in the sediment. Clutter is caused by different scattering phenomena: (a) scattering from randomly distributed discrete particles such as air bubbles in the water, gas bubbles in the sediment, fish and other marine life, and organic and inorganic matter; (b) scattering due to random temperature and density fluctuations; and (c) scattering from a randomly rough ocean bottom and sea surface. While *in situ* experiments are important, much can be learned about scattering physics from controlled laboratory experiments or from numerical simulations. The latter method permits the study of isolated scattering mechanisms as well as combinations of them. It can also be used to benchmark approximate theoretical scattering models and to test imaging algorithms. In addition, with the decrease in cost and increase in speed of computer workstations, relatively complicated numerical simulations can be performed inexpensively.

This grant was used to begin the development of code to study acoustic propagation through a shallow water waveguide. A two-dimensional waveguide with several different geometries was considered: (1) flat pressure-release surface and flat hard bottom surface; (2) flat pressure-release surface, flat hard bottom surface, and hard cylindrical scatterer; (3) rough pressure-release surface and rough hard bottom surface; and (4) rough pressure-release surface, rough hard bottom surface, and hard cylindrical scatterer. In addition, animations were created of a pulse propagating in the waveguide for the different geometries. These animations are available both on videotape and on the World Wide Web.

Code was completed to simulate propagation and scattering of acoustic energy within a rectangular computational domain with a depth of 6 m and range of 36 m for illumination by various sources, including a 20-element phased array with a center frequency of 7.5 kHz. The ends of the computational domain were terminated by absorbing boundaries to simulate propagation in an unbounded waveguide. The capabilities of the simulations are as follows: The top surface can have any prescribed profile and is assumed to be pressure release. The bottom can have any prescribed profile and is assumed to be acoustically hard. A single realization of a set of randomly rough surfaces with Gaussian statistics is currently used, but sloping surfaces or ones with deterministic features can be used as easily. Code was developed to generate randomly rough surfaces with either a Gaussian or power law spectrum. The water column can have a wide range of inhomogeneities. Currently up to 1024 different materials can be used to construct gradients in the water column or

to model discrete scatterers. The incident field can be modeled in a number of ways. The source can be constructed from a phased array of individual elements using the temporal description of the pressure and location of each element in the array. This permits the modeling of the radiation pattern over a broad spectrum—that is, the side lobes associated with the frequencies away from the "carrier" frequency are easily observed. When the radiation pattern due to a distant source is known, the actual space containing the source need not be included in the computational domain. The simulations presently record the field values at each point in the computational domain at each time step, allowing construction of 'virtual sensors' (individual points or receiver arrays, either co-located with sources to mimic transducers or distinct from sources to represent hydrophones) to provide the 'raw data' for image construction and analysis.

Finally, a broad range of rendering and display programs was written. These routines can be used to show the propagation of fields in the computational domain in near real-time (that is, the fields can be displayed as they are calculated). Such visualization tools can be used to gain insight into the manner in which fields propagate. These routines have been shared with other researchers doing temporal simulations.

## II. Conference Presentations

J.B. Schneider, S.L. Broschat, and P.J. Flynn, "Finite Difference Simulations of Propagation in a Shallow Water Environment," *J. Acoust. Soc. Am.*, vol. 96, no. 5, pt. 2, p. 3265, Austin, TX, Nov. 1994.

## III. Artifacts

[1] Videotape of an acoustic pulse propagating in a shallow water waveguide

[2] Web page with animations of acoustic pulse propagation in a shallow water waveguide

(URL: `http://www.eecs.wsu.edu/IRL/acoustics/acoustics.html`)

## IV. Journal Publications

K.L. Shlager and J.B. Schneider, "A Selective Survey of the Finite-Difference Time-Domain Literature," *IEEE Antennas Propagat. Mag.*, vol. 37, no. 4, pp. 36-56, 1995.